

EFFECTS OF INPUT TECHNOLOGY ON HUMAN WORKING MEMORY FOR MEDICAL
CHARTING INFORMATION

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ABSTRACT

In hospitals, medical charting systems have been historically used as a memory aide. Over the past decade hospitals around the world have been transitioning from paper-based systems to an electronic system as technology is developing. Previous research has focused on adoption processes and physician preferences but little research has been done on how the changing technology impacts the ability to complete charting tasks. Recent research has demonstrated a location updating effect on memory that explains as individuals enter a new space through a doorway they forget some of the information that was held within their working memory. This phenomenon has potential for significant negative effects in hospital charting when medical professionals elect to complete their charting activities away from the patient's bedside.

This research evaluated the effect of different input technologies and the effect of doorways (the location updating effect), on medical charting. Participants were shown videos of medical scenarios and asked to recall and input patient information on a medical chart presented as a paper chart or electronically on a tablet, and a laptop, in a balanced randomized order. They were allowed to take notes during each medical scenario video clip to generate a baseline of performance and understand what they had been attending to in the medical clip. Performance scores were then assigned based on the number of items accurately recalled after a one minute break during which they either entered a new room through three doorways, walked back and forth in the original room, or simply waited while seated. The items to be recalled included demographic information about the patient in the video, narrative information related to the patient's medical history, numeric data in the form of vital signs and current or prescribed medication data in a checkbox format. Results show that significantly more items were recalled to paper (13.5) compared to either the laptop (11.8) or tablet (9.7). There was no evidence of a location updating effect.

The first study showed that paper was the superior system for both recording notes and for recall, results were inconclusive in determining if this performance was attributable to the motor skills required by handwriting or not. The second study, following nearly the same experimental protocol, evaluated handwriting on paper (12.4 items recalled) and on tablets with the use of a stylus (9.9 recalled). It confirmed that paper was the superior method for note taking and recall. The implications of these findings and limitations of the study are discussed.

BIOGRAPHICAL SKETCH

Angela was born and raised in the Pacific North West. She attended the University of Idaho and earned a Bachelor's degree in Psychology and a minor in Architecture. She developed her passion for research through years of study in the field of Biological Sciences under the supervision of Dr. Larry Forney. She became interested in Human Factors and Ergonomics during her Senior year after trying out a number of other majors. Angela is interested in how technology and the environment work together to impact the human process of information storage and retrieval. In the future she hopes to apply knowledge of Human Factors research in an applied industry position helping to improve the quality of technology and facilitate improved user performance.

Dedicated to my parents, Dan and Shawna, thank you for always being my biggest fans.

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TABLE OF CONTENTS

Biographical Sketch.....	iii
Dedication.....	iv
Acknowledgements.....	v
Table of Contents.....	vi
List of Figures	vii
List of Tables.....	ix

Chapter One: Introduction

1.1 Human Memory.....	1
1.2 Memory & Technology	6
1.3 Memory & Environment	11
1.4 Medical Settings	14
1.5 Purpose of Current Research	24
1.6 Hypotheses	25

Chapter Two: Methodology: Study One

2.1 Participants	26
2.2 Research Design	26
2.3 Settings & Apparatus	27
2.4 Materials	28
2.5 Procedure.....	29
2.6 Data Analysis	32

Chapter Three: Results: Study One

3.1 Technology	34
3.2 Environment	35
3.3 Video Clip	36
3.4 Gender	38

Chapter Four: Discussion: Study One

4.1 Technology	39
4.2 Environment	43
4.3 Video Clip	45
4.4 Gender	46
4.5 Limitations	47
4.6 Study Two Rationale	49

Chapter Five: Methodology: Study Two

5.1 Participants	50
5.2 Research Design	50
5.3 Settings & Apparatus	51
5.4 Materials	51
5.5 Procedure.....	51
5.6 Data Analysis	52

Chapter Six: Results: Study Two

6.1 Technology	54
6.2 Video Clip	54
6.3 Gender	55

Chapter Seven: Discussion: Study Two

7.1 Technology	56
7.2 Video Clip	59
7.3 Limitations	60
7.5 Future Directions	61

Chapter Eight: Conclusion

63

References	65
Appendix A	71
Appendix B.....	73
Appendix C.....	75
Appendix D.....	76
Appendix E.....	78
Appendix F.....	79

LIST OF FIGURES

Figure 1. Baddeley's representation of Working Memory (McLeod, 2012)	2
Figure 2. Representation of lab space.....	28

LIST OF TABLES

Table 1: Mean items recorded and recalled based on technology used.....	35
Table 2: Proportion of items recalled based on technology used categorized by information type	35
Table 3: Mean number of items recorded and recalled based on environmental waiting condition.....	35
Table 4: Mean number of items recorded and recalled based on video clip.....	37
Table 5: Mean number of items recalled based on video clip categorized by information type	37
Table 6: Proportion of items recalled based on technology used categorized by information type	54
Table 7: Mean number of items recalled based on video clip categorized by information type	55
Table 8: Mean number of items recorded and recalled based on gender.....	55

Chapter One

Introduction

1.1 Human Memory

Humans rely on their memory systems in order to perform cognitive tasks. Memory aids in the process of learning and provides a performance tool that facilitates mental work (Logie & Della Sala, 2001). There are multiple subsystems of human memory (Repos & Baddeley, 2006; McLeod, 2008). Cowan (2008) describes the differences between the long term, short term or working memory stores. Long-term memory describes a system in which learned information is stored and accessed only when that information becomes necessary to the task at hand. Short term memory, synonymously referred to as working memory, describes a system in which information is held in the forefront of the brain for easy access as it is being learned before it makes its way into the long term memory store (Miller, 1956). This project will analyze the effects of technology and the location updating effect on working memory for medical charting.

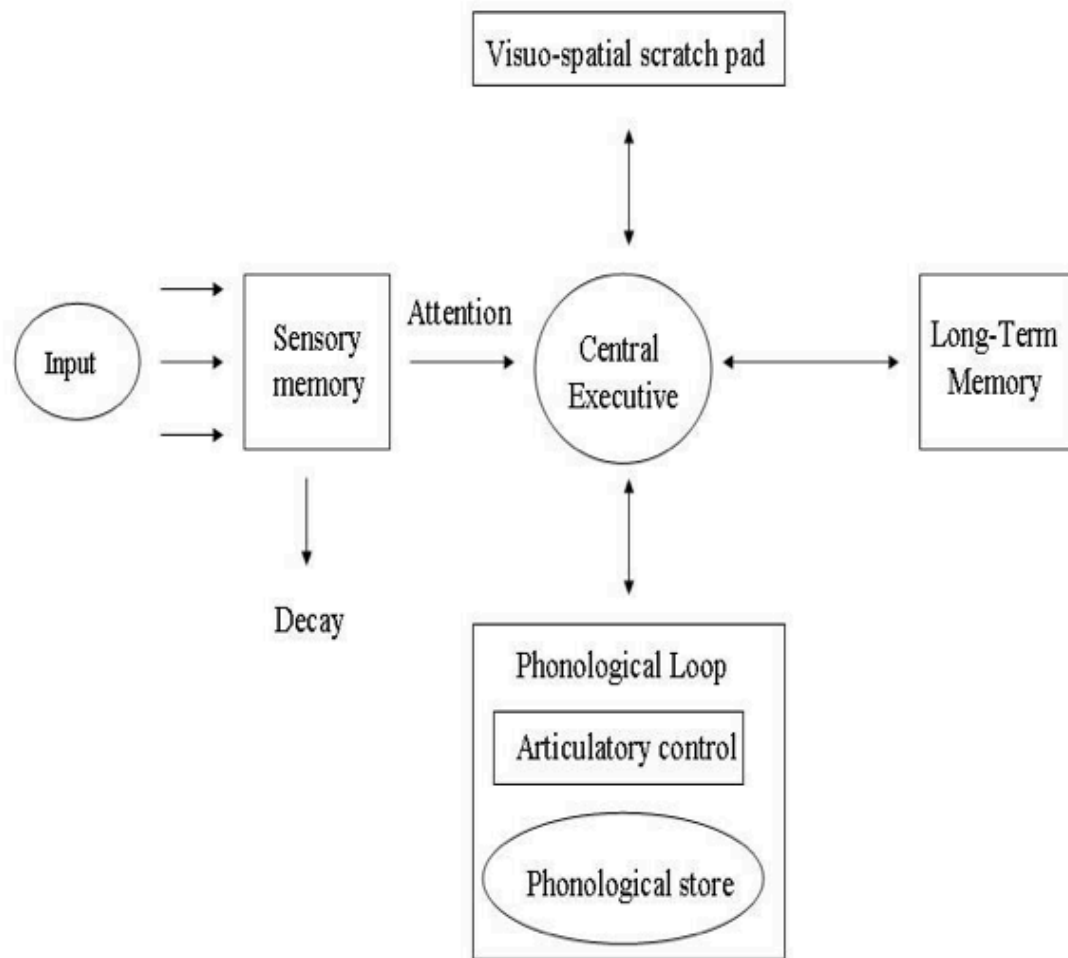


Figure 1: Baddeley's representation of Working Memory (McLeod, 2012)

A number of psychologists have described the working memory system over the years, identifying key components that work together to assist in the formation of new knowledge. Baddeley and Hitch (1968) developed the multi-component model of working memory, which delineates the functional aspects of human memory. Subsequent researchers have confirmed that the components of the memory system include a visuospatial sketchpad that stores visual stimuli in memory, a phonological loop that keeps auditory stimuli in memory and a central executive that runs the system (Baddeley, 1988; Buchsbaum, 2010; Repovs & Baddeley, 2006). The visuospatial sketchpad acts as a

graphical representation of information stored in working memory. It allows for the visualization of a certain image or text to be held within the mind and referred to for the purpose of recall. The phonological loop acts as a short-term rehearsal mechanism where information that is attended to is played back on loop to facilitate ease of recall. Rehearsal is an effective strategy to keep lists of information in mind (Baddeley, 1988). The central executive runs the working memory system, and it helps channel information to and from the long-term memory store (Logie & Della Sala, 2001). Each of these components works together for seamless transfer of ambient information to individual knowledge. Further, each system can operate concurrently until new stimuli displace the information held within human memory. An example, humans can rehearse a list of words using the phonological loop, while keeping an image in mind however once new auditory or visual stimuli is presented it displaces the information that is currently being attended too, if that information was not transferred to the long-term memory it is forgotten (McLeod, 2012).

Miller (1956) describes the span of short-term memory within the range of seven items. "Humans can process 7 categories for absolute judgments, hold 7 objects in the span of attention, and 7 digits in their immediate memory". Memory's capacity, however, is affected by the complexity of the information. For example, for binary information the span reaches 9, for monosyllabic English words, the span drops to 5. This range is where the capacity limitation of 7 ± 2 comes from. Miller (1956) also describes a chunking phenomenon that can increase the amount of information held within the capacity of working memory in discernable groups. When related stimuli are presented consecutively humans are only able to accurately maintain 7 ± 2 discrete items in mind, however, as they begin to group like items into larger chunks they are able to maintain more information. The human memory span can still only hold a fixed number of chunks, 7 ± 2 , although the complexity of the chunks can increase as seen with tasks pertaining to the reordering of

long strings of digits. Assigning new values to groups of 2 or more digits allows the individual to remember far more than if they simply try to remember each digit in a strand independently. Miller's (1956) work demonstrated that "the span of absolute judgment and immediate memory impose severe limitations on the amount of information we are able to receive, process, and remember."

Logie and Della Sala (2001) have defined working memory as "a system with limited capacity, which loses information over periods of seconds, whose contents are subject to displacement by new input, and which interacts and is supported by other parts of the cognitive system such as stored knowledge or products of perception". This system can be conceptualized as a short-term store where stimuli are often rehearsed and then recalled momentarily as required when the user performs their mental task. Working memory relies on the individual's knowledge base, and the more information the individual has stored in his or her long term memory stores the more readily the working memory system can attend to this information and call it to attention (Van der Linden, 1998). "Information that has been recently presented to the senses may activate traces in long term memory which then become available to components of working memory" (Van der Linden, 1998). Working memory relies on a knowledge base yet is able to improve through specific training (Klingberg, 2010).

Klingberg (2010) describes multiple training mechanisms that have been demonstrated to improve the quality of working memory. They are distinguished as explicit and implicit training. Implicit training provides gradual improvements and requires practice of tasks developed specifically to use working memory. Implicit tasks include memory tests for holding words in lists or remembering certain features of visual or auditory stimuli. Explicit training is the employment of new memory strategies such as rehearsal, or chunking to hold more information in mind. These strategies allow for more

rapid changes in the capacity of working memory. Klingberg (2010) describes a training system in which working memory tasks are completed for 30-40 minutes per day, 5 days a week for 5 weeks with the aims of increasing the number of visuospatial stimuli that can be held in working memory. Researchers who have used this training strategy have found 30-40% improvement in the capacity of working memory compared to 15% improvement in the control groups that received no specific training on strategies to improve working memory. For task specific training of working memory performance improvements can be seen after 2 weeks of active training approximately 30 minutes per day. Related research is still seeking to understand the optimal level of training and any limits to the capacity of improvements individuals are able to achieve through repeated training efforts.

Working memory relies on existing knowledge, and organizes new information into long-term memory stores. "Working memory is also considered to play an important role in transferring information from sensory input to long term memory and, in particular, to be closely involved in the learning of novel information" (Van der Linden, 1998). Richardson (2007) conducted a review on short-term memory in the literature, a key component in memory research had been familiarity or knowledge base on human's ability to recall information. In several studies where children and adults were asked to recall strings of words they were consistently better able to recall words that they could attribute a meaning too rather than nonsense vocabulary. This idea supports the processes involved during chunking, where new meanings are attributed to groups of information to increase the capacity of working memory. An example of this point is illustrated through imagining a random string of letters and then finding out a pattern exists, when separated by spaces groupings are formed that hold meaningful information in the form of a familiar acronym.

It is important to understand how the human memory system functions independent of influences of technology or environment before manipulating these factors

and evaluating their effects. As the field of memory research continues to grow more research is being done that evaluates direct influences, like technology and environment, which will be described in the following sections.

1.2 Memory & Technology

Currently, there are a variety of technological input devices at our disposal to facilitate the process of remembering information. Pen and paper allow for the manual formation of written information that is encoded in the brain and recalled when needed (Stausberg, Ingenerf, & Betzler, 2003). Electronic technology is also able to record and store information in many situations. Research on memory and technology has produced mixed results as to which storage system allows for the best functioning human memory.

Research on working memory for written text has evaluated the ability to locate specific words in a body of text. Kellogg (1996) proposed that human memory is subject to a text generation effect. This generation effect suggests that human's are more likely to recall information about a text that they wrote, opposed to a text that they read from an alternate author. The manual formation of information helps people recall certain aspects of the information, specifically, location of certain words or phrases within a larger passage. Bigot, Passerault, and Olive (2009) conducted a study that evaluated the ability to locate specific words that were generated by the participants themselves, or read from previously composed passages. In the conditions where participants were creating the text they were able to recall the location of key words with 20% more accuracy than chance levels would have predicted, supporting Kellogg's (1996) generation effect. Bigot et al. (2009) supported the claim that in generating words the brain creates a spatial layout of the text and refers to this mental image when later asked to locate specific parts of text within a passage (Bigot et

al., 2009). This work demonstrates the effects of the visuospatial sketchpad and its relationship to the formation of information.

Drew and Vogel (2009) found positive correlations between the capacity of working memory, and cognitive abilities, specifically intelligence levels and attentional resources. Reading span tasks, where participants are asked to recall the last word of each sentence in a passage, have been developed to assess intelligence level and performance on those tasks directly correlates to SAT performance. Attentional research focuses on the specific types of information that participants hold in their working memory capacity. These studies typically find that high performing individuals with larger capacity in their working memory are better at attending to relevant information than low performing individuals. Low performing individuals often have up to three times the amount of irrelevant information that acts as noise during a memory task (Drew & Vogel, 2009).

Understanding the tools used to help encode information into our working memory systems can be revealing. Naka and Naoi (1995) highlighted the role of motor memory, associated with manual writing, and its relationship with ability to freely recall information as compared to only reading and rehearsal of experimental stimuli. They found that “it is the writing action itself not the output that is important.” Through their experiments they evaluated the modality of encoding for its effect on free recall or recognition. They determined that writing outperformed reading recall for words, non-words and graphic designs, and for recognition writing outperformed reading for non-words and graphic designs. Overall effects of repeated writing on recall allowed for $M=7.36$ item ($p=.008$) improvement in recall compared to reading the stimuli then recalling the information. This result was not culturally dependent as it was found among all participants independent of race or gender. Additionally, they determined that the method used for encoding information directly relates to the performance of retrieving the information when done

using the same method, support of encoding specificity phenomenon suggesting that consistency between encoding and retrieval media establishes a stronger recall (Naka & Naoi, 1995).

After identifying the positive relationship motor memory has with our ability to recall information, Parkinson and Khurana (2007) determined just how far the process of manual writing can be broken down. They studied participants' ability to identify letters based by single strokes used in alphanumeric letter formation during manual handwriting. "Participants were significantly faster to identify letters from consistent temporal sequences, indicating that the initial part of the sequence contained sufficient information to prime letter recognition." The comparison between consistent stroke order and inconsistent stroke order proved to be significant ($p=.001$) that consistent stroke order allowed for 46ms faster recall. Further, when participants were asked to indicate how they formed each letter they could not say with certainty without mimicking writing the letter in the air. This indicates that the motor skills associated with writing may become innate once learned and motor knowledge takes over our ability to accurately perceive and describe the stimuli as we attend to it. Parkinson and Khurana (2007) concluded that people are "surprisingly unaware of well-learned and well-executed movements". They suggest that the perception of the stroke order primed letter recognition by activating traces stored in motor memory for well-learned skills among participants.

Motor memory can be used to help individuals remember the text they are writing, as shown by Longcamp, Boucard, Gilhodes, and Velay (2006) who conducted a study to determine if the orientation of newly learned letters could be remembered with any accuracy. This study evaluated the effects of learning from typing and from manual handwriting and found that when characters were learned from typing they were more confused with the mirror image compared to those learned and written by hand. The

experimental design consisted of two stages, a learning stage where the new letters were being learned and a testing stage where they were tested based on recognition, and discrimination. For those who learned through handwriting their correct responses were greater than for those who learned from typing by a score increase of 5.27 points, ($p < .05$). Recognition in this study was dependent on the nature of the motor activity experienced during learning. "The main result of this study was that learning the characters by handwriting facilitated their subsequent recognition." Handwriting uses different motor memory to create the characters while typing relies on the knowledge of the keyboard. Since the act of forming letters by hand, with a pen translates to the way the image appears on paper the connection between that motor skill is more salient than reaching the finger to a specific location on the keyboard.

The comparison in the literature between handwriting and typing highlights the benefits of handwriting, but there is still question as to why these two physical activities produce different motor memories and thus allow for different ability to recall information. Klein, Piacente-Cimini, and Williams (2007) found that motor memory from writing outperformed our ability to recall spoken words. Analysis of the process of working memory would indicate that spoken words should be just as easily recalled as written words since the process of encoding the information relies on two distinct neural pathways, the visuospatial sketchpad for the written text, and the phonological loop for the spoken text.

Each of the studies presented thus far, has demonstrated that handwriting is the superior way to encode information for ease of access and subsequent retrieval. The motor memories associated with the process of handwriting become so familiar to the experienced writer that they facilitate other memories related to the text. While these studies suggest that handwriting might be the preferred method for recalling information, most of these

studies have focused on recalling specific strings of numbers or visual information about newly learned symbols. Hardly any have looked at the ability to recall real world information in this way. The scope of the studies evaluated thus far rely often on strings of numbers or lists of words, not often on a hybrid combination of the two forms of information that are paired in a meaningful way as in a medical chart. In the present study, evaluation of information presented on a medical chart will indicate if there are any unique effects of recall between different types of information, narrative and numeric and if the relationship between that information spurs more thorough completion of the memory task.

While the studies described thus far have all advocated for the use of paper as the primary technology to record information to be recalled, research does exist that supports the efficacy of alternative technologies. Schoen (2009) found that note taking on personal laptop computers was the most successful for the purpose of note taking and recall when compared to paper. That research focused on the performance difference between handwriting and typing notes on academic information presented in a textbook or lecture format. Schoen found that typing information, especially in the lecture setting, was the best mode of information storage for subsequent recall, an average of $M = 12.12$ items were recalled from typed notes while $M = 9.76$ were recalled for handwritten notes ($p < 0.001$). In fact, typing for each condition of information presentation produced higher retention rates ($M = 11.84$) than paper ($M = 10.51$, $p = 0.004$). Possible explanations include the speed and accuracy of typing compared to handwriting, which allows for individuals to capture more information in a learning context and improve the performance scores during recall. This work, as it contradicts with previous support of paper as the most effective medium for note taking, specifically highlights the importance of further research in the field to determine

which technology is most suitable for real world settings, where rich information is being learned and transferred.

1.3 Memory & Environment

Environmental factors have been shown to influence working memory. A location updating effect, where there is a decline in memory after a change in location after passing through a doorway, has been demonstrated by (Radvansky, Krawietz, & Tamplin, 2011). Encoding specificity phenomenon posits that information learned in one environment is better retrieved when retrieval occurs in the same context. This phenomenon occurs because fewer retrieval cues are available in the new environment. Additionally the effort required to understand the new environment that has been entered can push information from the working memory store (Radvansky, et al., 2011). Encoding specificity can also refer to the relationship between how information was encoded and subsequently recalled. Research suggests that similarity between methods used in encoding and retrieval allow for the highest performance ratings (Naka & Naoi, 1995).

Radvansky et al. (2011) conducted a series of experiments in real physical space and virtual space to evaluate environmental impacts on memory. The first experiment required participants to move through a virtual environment picking up and placing a series of objects through using the arrow keys and mouse attached to the computer set up. Users would travel the same distance regardless of being in one large room or spanning 2 rooms after passing through a doorway. Mid walk they were prompted on identifying the object they were carrying or the one they had just set down, while carrying the objects they became invisible to the participant in order to test their memory with the prompts. Error rate data suggests that significantly more information was forgotten after a shift to a new location, .19, for positively identifying the item compared to .12 with no shift, and .22 for

correctly rejecting the prompt compared to .07 with no shift ($p < .001$). Their second experiment sought to identify location updating effects in a real environment, opposed to the virtual environment used in the first experiment. The error rates for positively recalling which object was in the box being moved were .28 for a shift in location, and .23 for no shift ($p = .02$), for correctly rejecting the prompt the rates were .21 for a shift, and .18 for no shift ($p = .06$). Their third experiment evaluated the theory of encoding specificity. In this experiment participants experienced shifting to one new room (shift), through one room to a second new room (double shift), walking in the original room (no shift), and returning to the original room after entering a new room (return). Performance scores indicate that memory was operating best in the no shift condition, positive error rate .11, negative, .07, as compared to the shift, .14, .12, the return .16, .14, and the double shift, .20, .17. The most important finding from this study demonstrates that memory performance is not improved upon returning to the location of encoding, suggesting that once a participant walks through any number of doorways regardless of the end point the information that was held within the working memory had already been displaced.

This issue becomes particularly relevant due to the fact that there is no regulation on hospital staff and medical professionals to complete their medical charting note taking processes that rely on memory of patient interactions in any particular room. From this study it would be assumed that the best place to complete the full medical chart would be at the patient's bedside or site where the information was encoded rather than leaving that room to return to a desk or office and complete the chart more thoroughly.

Anderson et al. (2009) showed the relationship between clinician role, clinical tasks and the technology of choice among 27 nurses and 8 doctors in a teaching hospital in Sydney Australia. The location of the charting activity was noted as a factor contributing to the selection of preferred technology. The technologies evaluated in this study included a

mobile computer on wheels (COW), a stationary PC, a tablet PC, and an ergonomic COW. 82.3% of the tasks were completed using COW, followed by stationary PC's then tablet PC's and lastly the ergonomic COW. "Most clinical tasks (49.1%) were completed in a patient's room, followed by the corridor (35.2%), the doctors' office (8.1%), a patient's bedside (4.3%), the central workstation (3.0%), and the medication room (0.2%)". Nurses completed 56.7% (doctors completed 29.1%) of their charting activities in the patients' rooms and 35.8% (doctors 57.3%) in the hallways. Only 3% of charting activities took place directly at the patient's bedside. Paper was being used as a work around to the electronic systems of medical charting. The primary observed usage included transcribing medication notes at a COW workstation, before heading to the medication room to prepare the medication where stationary computers were provided. This study highlights the necessity of mobile devices for input of medical information, however it demonstrates areas where the design of each interface can severely limit the ability to chart effectively if not properly adjusted for activity type, or user preferences. Many of the reported issues with the mobile systems included the formatting of the information that was necessary to complete clinical tasks, along with the difficulty in carrying a tablet through the hospital opposed to pushing a cart that has a computer workstation mounted on it. Implications for future design rely heavily on the preference of the medical staff, and training programs developed to assist in the transition to an electronic system.

Radvansky et al. (2011) uncovered the effects of passing through doorways, and the negative impact that action had on human working memory both in physical space and virtual space. With that knowledge it is clear from Anderson's (2009) study of where physicians are electing to complete their charting activities that a study is necessary to evaluate the relationship of environmental influences of passing through doorways while

holding more detailed specific medical information than the standard memory testing information that was used by Radvansky et al. (2011).

1.4 Medical Settings

It is important to understand how technology and the environment may influence human memory and performance in contexts, such as hospitals, where memory is heavily relied on. Studying medical charting provides a system in which memory is required for accurate performance.

Memory is a crucial system to evaluate in workplace settings where information is classified as highly important. Hospitals are one example among many, where memory is relied on heavily as medical professionals are interacting with patients and forming diagnostic decisions and plans for developing medical care. In hospitals, medical professionals rely on charting systems to take notes on patient characteristics and symptoms (Freudenheim, 2012). These charts are often shared between many members of the medical team and must be accessible to all involved in forming the plan for care (Feufel, Robinson, & Shalin, 2011). "The relationship between better medical charting and better medical care could lead to new ways to monitor and improve the quality of medical care. The more complete the charting is, the better the care provided" (Dunlay et al., 2008).

Over the past 10 years hospitals have been slowly transitioning the technology used to record information on medical charts (Freudenheim, 2004). They have gone from the traditional paper based system to an electronic system relying at first on laptops and now more pervasively on tablets (Hafner, 2012). Research on this transition highlights some observed performance impacts, discusses financial implications for medical professionals, and changes to the way medical professionals are recording and accessing information (Hatton, Schmidt, & Jelen, 2012; Hillestad et al. 2005). No study has yet uncovered the

effects of the technological systems on humans' ability to recall information. This oversight if not addressed could lead to a variety of issues in the medical system where the medical professionals are no longer making the most attentive decisions. The United States government has a budget of up to \$20 billion to incentivize the adoption of electronic medical record systems in hospitals across the nation by the end of 2014 (Hatton, Schmidt, & Jelen, 2012; Hillestad et al., 2005). Additionally, research by Wang et al. (2003) has determined that updating to electronic medical records can lead to a positive ROI for hospitals across the nation, further incentivizing this transition.

Ludwick and Doucette (2009) provide a clear definition for an electronic medical record that can be referred to for the purposes of this research.

"An Electronic Medical Record (EMR) is a computerized health information system where providers record detailed encounter information such as patient demographics, encounter summaries, medical history, allergies, intolerances, and lab test histories. Some may support order entry, results management and decision support" (Ludwick & Doucette, 2009).

The complex nature of information that is stored within the EMR system requires focused attention of medical professionals to complete charts accurately and avoid error.

There are many issues discussed by Steward (2005), regarding the transitions hospitals are undergoing with the adoption of new EMR technology. Hospital professionals are worried about the privacy of the patient files, the impact of their workflow in learning and adapting to a new system of information recording, how their relationships will change with patients, understanding and adapting to any changes in quality of care, efficiency and liability. As physicians transition to reliance on technology for their note taking many fear their confidence in overall diagnosis will be impacted (Steward, 2005). Like the main goal in practicing medicine these records were supposed to do no harm and improve the quality

of medical care. Benefits of using the systems include localized accessible patient information, efficiency of patient research, and a system of alerts put in place to aide in the decision making process for diagnosis (Feufel et al., 2011).

As charting systems change extensive training is required for ease of transition. “The intensity of training, the timing of the training and the availability of training and support post-implementation all affected user experience”. Training and follow up access to developers of the electronic medical record systems allows for the most positive transition (Ludwick & Doucette, 2009). With out adequate support from the designers of the system medical professionals could be facing errors that can lead to life threatening situations.

Proponents of health information systems suggest that adoption of EMR leads unconditionally to a reduction in adverse medical events. Research by Ludwick and Doucette (2009) showed that error sources resulted from training issues, implementation issues, and the length of time needed to become familiar with the nuanced system. Access to thorough training and continued support from IT can help mitigate some of the initial errors reported during early usage of EMR systems, however this support may not be enough if physician performance is declining. “Health information systems do not improve or erode efficiency, quality of care, or patient safety. The quality of the implementation process is as important as the quality of the system being implemented” (Ludwick & Doucette, 2009). The main theme of challenges from the providers’ perspective is loss of control, slowed workflow, pace of technology obsolescence and cognitive distractions from interacting with computer rather than with the patient. The loss of control can be detrimental to the practice of medicine however this phenomenon may only be experienced by practicing physicians who began using paper and made the transition to the EMR system (Hatton et al., 2012; Freudenheim, 2004; Grossman & Cohen, 2008). It is clear that the medical professionals and the United States government have opposing viewpoints when it

comes to best practices for adoption policies of the new electronic medical record system. Since experiments are often difficult to conduct in medical settings, most of the research to date has been about the debate between the support and reluctance to accept this nation wide systematic change to one of the fundamental processes of medical care.

Human factors research is interested in understanding how an “EMR-enabled work system alters cognitive performance for the better or worse.” Cognitive performance can be influenced by many factors including improving accessibility of the medical chart to include more individuals responsible for contributing to it, and improving the system of communication between them. Performance can decrease by changing the nature of the tasks involved in charting and making any component of the task more difficult. Holden (2011) found physicians reporting that EMR systems “disturbs communication and creates sterile narratives populated by checkbox responses.”

Holden (2011) developed four main criteria on which to base the comparison between paper and electronic records. These are “omnipresence/access, manipulability/flexibility, integration rather than fragmentation, and awareness of the procedures that are linked to different systems.” Omnipresence refers to the availability of patient information and the localized nature of that information. In paper charts extraneous documents could be added into the chart and bits and pieces of the chart could be found through out the hospital, depending on who was working with the chart. Manipulability refers to how easy the input system is and how well information can be changed once in the chart, it specifically refers to how well the users can get information from their working memory store into the system before it is lost. Integration is similar to omnipresence in that it refers to compiling complete documents that are accessible to all. Finally, physician awareness is important in determining length of training necessary to implement new systems (Holden, 2011). Depending on the skill level of the physicians at a

hospital and their engagement with technology the transition could become a slow and cumbersome process. To date, there are no guidelines that can be applied to the adoption policies of new medical charting systems.

Electronic medical records connect many collaborators included in diagnoses and increase their accountability since their actions become immediate and transparent (Brooks & Erikson, 2012). Practicing physicians must be retrained of technical skills required to complete a chart as the medium changes since often they are not adequately trained in these methods through their formal education. Many schools of nursing do not have the technology to prepare students for use of electronic systems in future employment (Brooks & Erickson, 2012). Electronic medical records can even undermine the physicians' ability to diagnose confidently with out relying on the database of previous cases since it eliminates the framework of a single person's experience and allows multiple past cases to be called upon (Han & Lopp, 2013; Reich, 2012; Freudenheim, 2012). Factors such as low physician acceptance of the EMR system, low availability of hardware as well as lack of specific software features can negatively affect transition from a paper-based system to an electronic system (Pourasghar, Malekafzali, Koch, & Fors, 2008).

In hospitals in the past paper charts were deemed superior due to the known benefits of manual writing (Pourasghar et al., 2008). Now as hospitals are transitioning to electronic systems the healthcare providers are being forced to develop a new skill set. The transition from a paper based charting system to an electronic system requires all subscribers to develop a new level of skill, or an expertise in charting with their new technology. According to Ericsson and Towne (2010) the difference between experience and expertise can impact the ability to recall information with accuracy. "Behavior generation in initial stages of practice can be slow and associated with failures of memory retrieval and errors of execution." Time since the skill is acquired has been correlated with

poor performance since the skill can be lost. After about 50 hrs of training and practice skills become automated and individual control over performance can be lost. Frequent training intervals or workshops should be required so that staff using the technology continue to learn and keep the process far from automated as possible to encourage thought while the charting activities are being completed (Ericsson & Towne, 2010).

It is understood that the skill set necessary for completing electronic documentation differs from that of hand written notes, there have been little research to determine the competencies of writing and reading from the electronic platforms. Traditionally, medical students are taught to input medical information to a chart on paper placing an emphasis on accuracy, thoroughness, organization, sound interpretation, and logical coherence. Writing concise, high quality chart notes has been a core skill in medical education. Physician preference and formatting complexities can all impact the successful implementation of future EMR systems (Han & Lopp, 2013).

While most research has focused on the perceptions of the individuals involved in the transition of the medical charting system, Shabbir, Ahmed, Sudhir, Scholl, Li, and Liou (2010) evaluated tangible performance effects in time spent during medical charting. They evaluated a hospital that had recently undergone the transition to the EMR system. After analyzing staff with no computing experience, there was no statistically significant difference in the time spent for documentation between electronic and paper records. The mean time spent in documenting electronic records was 0.92 min ($p<.05$) longer than in paper records (Shabbir et al., 2010). This finding was particularly interesting as it contradicted with many of the concerns expressed by medical professionals on how the electronic system would slow down their work flow and become detrimental to their overall practice of medicine. The fact that the electronic system neither speeds nor slows the process of medical charting is worth evaluating in future research.

Previous research by Pollard et al. (2013) highlighted the importance of consulting the physicians before developing a system physicians are required to use on a daily basis. Pollard et al. (2013) found paper charts were often conducive to free form notes while electronic charts became more template based and imposed a new structure of organization onto the professionals using them. Since charting activities can take up to 33% of a physician's day it is important that the interface be well designed to avoid challenges to the users. The debate between structured and free form notes relies on the preferences of the team who will be using the system. "Narratives are important part of the paper based systems: These narratives include the core sections of the medical record, such as patient history, physical examination, progress notes, procedure reports, and discharge summaries" (Sharda, Das, Cohen, & Patel, 2006). In some contexts when there aren't regulations on the type of information that is required to be recorded electronic charts can encourage professionals to complete them more thoroughly since their design is often more reliant on check boxes than free response (McAndrew, Ban, & Playle, 2012).

Sharda et al. (2006) studied the effects of narrative based text entry on recall between new and experienced physicians. They found that recall and experience level had a distinct relationship that predicted the more experienced the physician the better able they were to assess information from the narrative rather than the structured chart, suggesting that structured chart is best for novice and mid level physicians. This study helped to identify clinically relevant information that can be used to structure medical text for the EMR and potentially improve recall and reduce errors. The design of the EMR interface becomes crucial to evaluate for its impacts on performance and where the tradeoffs lie between paper and electronic methods (Sharda et al., 2006). This study built off the notion that narrative information was easier to recall and became an important factor contributing to the final diagnostic decisions made by the medical professionals.

Some hospitals like the one Siika et al. (2005) described in Kenya, have been using the paper and the electronic system of record keeping in conjunction. Paper allows the professionals to take quick detailed notes to aide in collaboration, and entering them into electronic systems at the end of the day allows all of the information to be accessed and shared by multiple users, where the traditional paper chart was less accessible (Siika et al., 2005). These hospitals have achieved the best of both worlds by utilizing paper as a memory aid during the transition to electronic documentation. Paper and electronic charts can compliment each other. “Medical professionals should be cognizant of the possible discrepancies between paper and electronic information and look toward combining information from both records whenever appropriate” (Stausberg, Koch, Ingenerf, & Betzler, 2003). It ultimately depends on the goals of the implementers whether unified access is most important and a new platform of communication, because there are often reports of paper being used more frequently in hospitals where they are now asked to use electronic charting systems. Regardless of the design of the EMR technology, paper is still pervasive in many instances because it is the system most people are comfortable with.

It is important to understand the reasons for the prevalence of paper in the transitioning electronic systems. There are many opinions related to the change and multiple researchers have addressed the sentiment of the medical staff regarding the change, Saleem et al. (2009) went further in uncovering the reasons medical professionals were still using paper. They found that paper use was related to the following categories: efficiency, knowledge/skill/ease of use, memory, sensorimotor preference, awareness, task specificity, task complexity, data organization, longitudinal data processes, trust & security. Their paper highlights at least 17 examples of paper being used as a reminder where an electronic system would be considered cumbersome. “In the transition from paper to electronic medical records, the role of paper has changed from a long- term storage medium

to an important, temporary memory aid and disposable display device”. Essentially physicians were using paper in lieu of reliance on their own working memory store due to the nature of the medical information to be remembered. Some physicians that were interviewed expressed that paper was a crucial element to their success related to charting. Previously it was thought that using paper concurrently with an EMR system was a result of poorly designed EMR interface, poor integration into the clinicians’ workflow and an inconsistency with the design and the understanding of the users (Saleem et al., 2009). As time passes, many professionals realize that the reliance on paper comes from a deep user preference and the desire to keep all records accurate as possible without relying on a potentially faulty human memory system or trusting an unfamiliar electronic system. Further, the use of EMR systems has increased prevalence of copy and paste exams and demonstrated a noticeable decrement in the collaboration between physicians and their interactions with patients (Thielke, Hammond, & Helbig, 2007). Theilke et al. (2007) found that 13% of those surveyed had copied and pasted information they had previously recorded about medical exams and 3% had copied and pasted from another source entirely. One in Four exams had been copied and one in seven was copied from a test 6 months earlier. Copying and pasting of information becomes a huge security concern and also can become the basis for medical fraud (Simborg, 2008).

The nature of the paper chart and the physical ‘hand off’ creates meaningful points of interaction and collaboration between doctors and nurses that are not present with the use of EMR. Further, the social implications of introducing technology into the bedside care of a patient, creates another barrier to communication between physicians and patients. Consider the social ergonomics of the device and what message are being transmitted when conversing with patients while on computers or tablets compared to those physicians who have a piece of paper in their hands (O’Malley, Grossman, Cohen, Kemper, & Pham, 2009).

In all settings, not only hospitals an individual who is interacting with technology projects a different image of one who is holding or interacting with a piece of paper and may appear less approachable thus impacting the quality of the communication.

The lack of standardization for how physicians are expected to communicate using EMR as a platform leads to additional issues in collaboration and lost opportunities for interaction. Often doctors are now faced in situations where they experience cognitive overload while trying to navigate the complexities present in the EMR system, this is taking a negative toll on their interactions with their patients (O'Malley, Cohen, & Grossman, 2010; Ofri, 2011; Hafner, 2012; Horowitzm, 2012). Doctors who are new to using the electronic medical record system have not developed the level of skill to maintain a natural flow of communication with the patient while completing their charts, they often spend time searching through menus and lists to input data rather than discussing health concerns with their patients (Cassil, 2010; Chen, 2010).

The electronic medical records require a certain level of skill for interaction. "Paper records offer the further advantage that they can be easily developed. If they do not suit an interaction, any paper form can be customized by a healthcare professional, even if this involves no more than making handwritten annotations." There is a noticeable drawback to using electronic systems when there is a divide between the creator and user. Since the doctors don't know how to reprogram or format the chart they experience a loss of control they once had when using paper, which becomes frustrating and at times debilitating (Morrison, Fitzpatrick, & Blackwell, 2011).

There have been no studies published yet, that scientifically measure the quality of documentation of electronic records. Doctors who are implementing EMR systems with out adequate training or continued support are facing challenges practicing medicine to the best of their abilities. Their roles in hospitals shift and they become more consumed by

paperwork and navigating the challenging interfaces rather than spending time one on one with patients and achieving appropriate diagnoses (Brown, 2011). The electronic distractions and issues with relearning basic note taking are becoming more apparent as more hospitals are being evaluated (Richtel, 2011).

1.5 Purpose of Current Research

The focus of the current research had multiple aims. After assessing the basic human factors performance gap in medical charting research the main interest became understanding the relationship between the input technology and the changing environmental effects on the natural human processes of working memory that is used during the completion of medical charting activities. Through a series of two experiments I was able to determine the effects of input technology on the storage and retrieval of novel simulated real world information in the field of medicine, I was able to understand the effect of the environment in the roll of completing medical notes, and determine any demographic effects that may impact memory performance such as gender.

The present study sought to evaluate the technological devices used in memory formation, comparing paper, tablets and laptops, and look at an environmental effect when it comes to the encoding and retrieval locations of specific medical information, specifically the effects of passing through doorways. Demographic variables relating to participant age, gender, field of study, and standard processes relating to personal memory support were evaluated too. The stimuli used for this study were medical information presented in video form and assessed through performance in completion of medical charts that were identical across technological mediums, paper, tablet and laptop. Participants were allowed training time to become familiar with the technology and format of the medical chart before data

collection began. Analysis of current work highlights paper as the superior system for note taking in hospital settings where memory is a crucial aspect of performance.

1.6 Hypotheses

H1: Quality of note taking and memory formation is dependent on technology used.

H1a: Familiarity with technology provided will produce higher performance for that technology compared to others. Based on the participants recruited, their age level and self reported technology of choice for memory purposes; the paper condition should outperform both the tablet and the laptop in quality of notes and amount of information recalled.

H1b: The motor memory associated with handwriting will produce higher levels of recall for the paper condition compared to either of the electronic conditions, tablet or laptop.

H2: Environmental factors exist in contributing to overall amount of information humans are able to recall. The difference between encoding and retrieval is important, significantly more information will be recalled when asked to recall the information in the same spot as encoding stage, less will be recalled when asked to enter a new room before recall due to the previously studied location updating effects.

H3: Familiarity of information will aide in recall. The video clip that rates the highest on familiarity among participants should also be the video clip where the most information was recorded and recalled.

Chapter Two

Methodology: Study One

This study evaluated the technology and environmental factors influencing the ability to recall novel medical information onto a medical chart. One scenario presented a traditional paper based chart while the other two utilized the same chart on electronic platforms, a tablet or laptop computer. After the initial viewing of the medical video clip and completion of note taking participants experienced one of three environmental waiting conditions in randomized order, waiting while seated, walking in the experimental room, or walking to a new room.

2.1 Participants

Forty-eight students from Cornell University (24 male, 24 female) were recruited through an electronic posting on a University recruiting site (SUSAN) to participate in this study. Participants received \$10 payment for their time after completing the 30 min study.

Participants' ages spanned from 18-28 years old with an average age of 21 years old. These participants were most familiar with using paper or laptops although 6 of them had used tablets on a regular basis, at least once a day. 70.1% of them reported preference towards paper for tasks specific to recall while the remainder preferred laptop use, not one participant reported using tablets as a memory aide.

2.2 Research Design

A repeated measures design was followed. Two independent variables were tested: the technology used (paper, tablet and laptop) and the environmental condition (seated wait, walk within the experimental room, and walk to a new room). Twenty-four unique combinations of video clip, technology and environmental wait conditions were created and

each combination was randomly assigned to one male and one female for this experiment. The conditions were completely counterbalanced so that each video was shown for each of the different technologies and environmental wait condition to avoid any effects of the quality of the video.

The dependent variable was the number of items recalled to a blank chart, presented on paper, a tablet or laptop, after viewing the medical video clip, while taking notes on paper, tablet or the laptop, and experiencing the environmental waiting condition (walking in the same room, walking to a new room, or waiting while seated for the same duration). The blank charts provided after the environmental wait condition were always the same technology, paper, tablet, or laptop, as was used during the first stage of note taking.

2.3 Setting & Apparatus

Data was collected in The Human Factors and Ergonomics Performance Laboratory in the Human Ecology Building on Cornell's Ithaca Campus. Videos of medical charting scenarios were played using the most recent version of Windows Media Player on a Dell Desktop computer Optiplex GX620 series with an Intel Pentium 4HT processor. The computer ran Windows XP professional version DT7570. The Monitor for viewing the videos was 19 inches and the model was Dell 1907 FP. The speakers used were Dell AS501 model.

The lab is 480 square feet. A diagram representing the floor plan of the lab can be viewed in figure 2.

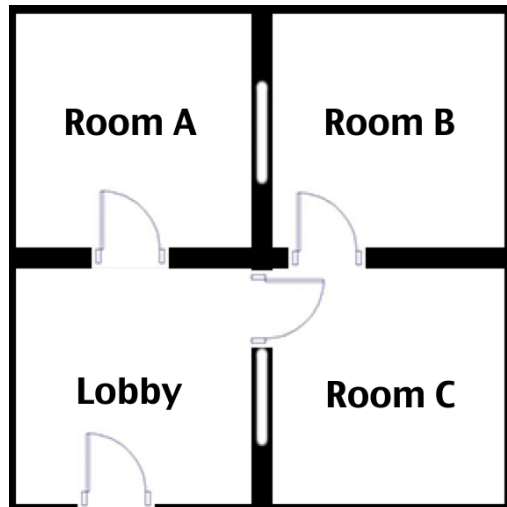


Figure 2. Representation of lab space.

Participants entered the laboratory through the lobby space and were directed into room B to begin the experiment. This room has a single doorway and interior windows to room A, and a window to Room C.

2.4 Materials

Three video clips were edited to fit a 2 min span from full medical charting scenario clips produced by Montgomery College (<http://www.youtube.com/watch?v=Bkoic2dLFmY> offered as public domain on YouTube without copyright. For the laptop medical chart participants were provided with a laptop (MacBook6,1 laptop running Microsoft Word 2008 for Mac, version 12.3.6 (130206)). The screen size for the laptop was 13 inches. For the tablet chart they were provided with a Microsoft Surface RT tablet that was also running Microsoft Word 2013. The dimensions of the tablet were 10.81in width x 6.79in length x .35in depth. Screen resolution was 1366 x768 pixels, with a 16:9 aspect ratio of the viewable screen size. For the paper chart this was printed on an 8.5 x 11in. sheet of paper and completed with a Bic ballpoint pen.

2.5 Procedure

Once the participants entered the laboratory they were directed back into room B where they sat at the computer and completed the consent form (Appendix D). The consent form was read aloud to them while they followed along, allowing for time to ask any questions before the experiment began. Upon obtaining consent each participant was presented with the standard chart format on the tablet. Participants were given as long as they needed to scroll through the chart and practice typing in order to become familiar with how to use the tablet. They typically took about 1-2 minutes practicing typing and looking over the layout of the information on the chart. Participants then watched the same 2 min training clip and practiced medical charting on the tablet in order to experience watching a video and filling out a chart simultaneously prior to the actual data collection. Since familiarity was assumed with the laptop and paper conditions, no training prior to the data collection was required for these technologies. This assumption was validated through questionnaire data that supported the level of experience being greater for both the paper and laptop technologies compared to the tablet.

Participants were informed that they would be recording notes while viewing the medical clips and practicing charting before they would have to break for a moment to complete an alternate activity, such as walking, sitting or entering a new room, and then fill out the chart a second time based on their ability to recall the information. Participants were not allowed to pause the video clip for any circumstances other than a technical malfunction with tablet resulting in a closed chart or them accidentally minimizing the document without knowing how to open it again. In any instances where the clip had been paused due to a technical difficulty the problem was quickly fixed, since the experimenter was sitting in the room with them the entire time, and the video was resumed from the place where it had paused.

All participants used all three technologies, paper, tablet and laptop while charting. They each also experienced every environmental condition, waiting, walking within the room they viewed the video and walking to a new room. Every participant watched all three medical clips and was presented the information in combination with the technology and environmental factor in a balanced randomized order. Participants watched all 3 videos of the medical charting scenarios in Room B. For one of the conditions after viewing a video they walked to the Room A, which had a similar size and layout to Room B, to recall the information. As participants walked to Room A they had to open and close three doors between the two rooms while carrying whichever technology they were using to chart information for that particular video.

Participants were randomly assigned to conditions upon arrival; each participant experienced all three charting technologies, paper, tablet and laptop, presented in a randomized order. They watched all three video clips also in a randomized order and they experienced all three of the environmental waiting conditions in a randomized order. Each of the waiting conditions took one minute so the participants were expected to hold the information they had encoded while taking notes and watching the medical clip in their working memory for a full minute before being given a blank chart to document their performance on information they could recall. The three waiting conditions at the end of the video clip were as follows:

- the participant remained seated and waited for exactly 1 minute before being presented with the blank chart on either paper, the tablet or the laptop, and being asked to fill the chart out based on the video they had most recently watched.

- the participant was asked to walk for one minute within the same room before being seated to fill out the blank chart on the video they most recently watched.
- the participant was given one minute to walk into the second experimental room A, passing through 2 rooms and 3 doorways along the way before they were seated and asked to fill out the blank chart about the most recent video that was watched.

There was a one minute break between each of the videos and charting conditions that was used to cue the next video, and participants were given as much time as necessary after the clips stopped to complete their note taking on the first chart before their break began. While they were filling out their second chart they were asked to indicate to the researcher when they were finished so they could begin their 1-minute break before watching the next clip.

Once the participants had completed filling out each of the charts they were asked to complete a post experimental survey indicating their overall use of the three technologies for note taking, their preferences for recall and their overall understanding and enjoyment of the three video clips. See Appendix E for the survey.

The entire procedure lasted approximately 25 minutes. Each video contained more information than could be recalled in the normal capacity limitations of working memory without using an information recording device. Two of the videos had 42 potential items to be recalled, and one had 21. This was done intentionally to determine if there was an effect of amount of information being presented in the certain time frame.

Note taking on the tablet was completed using the on screen Qwerty keyboard. Participants could touch different sections of the chart to move the cursor and begin typing

or they could tab through their options using the tab key on the keyboard. While the keyboard was visible a significant portion of the screen was obstructed from view.

The experimental design and procedure was approved by the Institutional Review Board of Cornell University.

2.6 Data Analysis

Performance scores were assigned for both charts during the experimental condition. The first score reflects the number of items of information that the participant recorded while watching the clip and charting simultaneously and the second score relates to the number of items of information that were accurately recalled after experiencing the environmental wait factor and having a minute break between viewing the video and recalling the information.

Mixed model analysis was completed using multivariate statistical analysis software (SPSS version 21) to compare the number of items reported on the first charts (the note taking conditions- encoding stage) to the environment, technology and video clip. The same mixed model ANOVA was used to compare the number of items reported in the second chart (the retrieval condition) as well as to compare to the difference between number of items reported or their overall performance score. Pairwise comparisons were made for main and interaction effects. Bonferroni adjustment was used to control for the large number of comparisons being made.

The dependent variables that will be presented are:

DV1: Items reported in Encoding stage

DV2: Items reported in Retrieval stage

The results will be presented simultaneously for Encoding and Retrieval, highlighting the performance differences across the independent variable categories. Further they will be categorized by technology, environment, and then clip taking into account gender when

there was a significant difference. Additionally, information type will be presented and categorized based on which technology allowed for the greatest level of response based on the way the information was presented, and further to categorize the information composition from each clip.

Chapter Three

Study One Results

Encoding and Retrieval

3. 1 Technology

Significantly more items were recorded on paper for both encoding, while watching the video clip ($F(2,79.84)=17.26$ $p<.001$) and recall ($F(2, 79.63) =7.34$ $p=.001$), than for the tablet or laptop (Table 1). The estimated marginal mean values and standard errors are presented in Table 1. The results of the pairwise comparison for the encoding stage showed a significant difference between paper and tablet with $M=3.7 \pm .6$ more items being recorded on paper ($p=.000$), laptop and tablet ($p=.006$) with $M=2.1 \pm .6$ more items being recorded on the laptop than the tablet, and laptop and paper, with $M= 1.7 \pm .6$ more items being recorded on paper ($p=.029$). During the retrieval stage $M= 1.9 \pm .5$ ($p=.001$) more items were recalled to paper than the tablet. $M= 1.4 \pm .5$ ($p=.024$) more items were recalled to paper than the laptop, however there was no significant difference between the tablet and the laptop.

Table 2 shows the relationship between the number of items recorded on the first chart that was used for the encoding stage, and the number of items that were accurately recalled. Average values are presented for each of the four main categories of information type across all technologies. The four categories of information were all related to patient information from the medical charting videos, medication information was presented on the charting template as a checkbox category of information, numeric data was capturing information related to vital signs, demographic information spanned both numerical and narrative information and the remaining category, narrative information describes any remaining narrative about the patient in each video. Error categories are presented along the last row of the chart and will be explained further in the discussion section.

Table 1: Mean items recorded and recalled based on technology used

Technology	Encoding		Retrieval		Difference
	Mean	S.E.	Mean	S.E.	
Paper	13.5	0.5	10.3	0.5	3.2
Tablet	9.7	0.6	8.4	0.5	1.3
Laptop	11.8	0.6	8.9	0.5	2.9

*Based on Estimated Marginal Means

Table 2: Proportion of items recalled based on technology used categorized by information type.

	Medications	Numeric	Demographic	Narrative	Total
Paper	1.00	0.68	0.97	0.77	.80
Tablet	1.04	0.64	1.18	0.88	.90
Laptop	0.95	0.66	0.93	0.75	.78
Average	1.00	0.66	1.03	0.80	
Error Type	Omission	Reversal	Generation, Reversal & Omission	Omission	

*Bolded values indicate generation of accurate information over the minute break.

3.2 Environment

There was no statistically significant effect of the 1 minute environmental wait condition on the number of items recalled. Table 2 shows mean values for number of items recorded during the encoding stage, and retrieval, highlighting their difference.

Table 3: Mean number of items recorded and recalled based on environmental waiting condition.

Environment Wait Condition	Encoding		Retrieval		Difference
	Mean	S.E	Mean	S.E	
Wait	11.6	0.6	9.2	0.5	2.4
Walk in Rm. B	12.1	0.6	9.4	0.5	2.7
Walk to Rm. A	11.3	0.5	9.0	0.5	2.3

*Based on Estimated Marginal Means

3.3 Video Clip

During both the encoding and retrieval stages the video clip had a significant effect on number of items recorded (encoding, $F(2, 79.84) = 61.71, p < .001$; retrieval, $F(2, 79.63) = 34.44, p < .001$; Table 3). The total number of items presented in the Diabetes clip was 20, and the total number of items presented in the other two videos was 42. During the encoding stage each pair of videos was rated as significantly different. There was a mean difference of $M = 4.7 \pm .6$ more items being recorded while watching the Post Partum video compared to the Diabetes video ($p = .000$). A difference of $M = 6.9 \pm .6$ more items being recorded during the Medical Error clip as compared to the Diabetes clip ($p = .000$). A mean difference of $M = 2.1 \pm .6$ more items were being recorded during the Medical Error clip than the Post Partum clip ($p = .005$). The pairwise comparison for the retrieval stage showed a significant difference between the diabetes clip, but not the other videos. During retrieval $M = 3.2 \pm .5$ more items were recalled while watching the post partum clip compared to diabetes clip ($p = .000$), and $M = 4.1 \pm .5$ more items were recalled during the medical error clip than the diabetes clip ($p = .000$). There was no statistical difference between the number of items recalled for the post partum or medical error clips: medical error clip $M = .8 \pm .5$ more items were recalled than the post partum clip.

According to the post experimental survey results the Diabetes clip rated the highest among memorability, interest, understandability, enjoyment and overall video quality with an average score of .63 out of 1. The score for post Partum was .55 and for Medical error .52.

Table 4: Mean number of items recorded and recalled based on video clip

Video Clip	Encoding		Retrieval		Difference
	Mean	S.E.	Mean	S.E.	
Diabetes	7.8	0.5	6.8	0.5	1.0
Post Partum	12.5	0.6	10.0	0.5	2.5
Medical Error	14.7	0.6	10.8	0.5	3.9

*Based on Estimated Marginal Means

Table 5: Mean number of items recalled based on video clip categorized by information type.

Diabetes	Medications (0)	Numeric (2)	Demographic (7)	Narrative (11)	Total (20)
Paper	0.21	1.43	3.93	1.71	7.3
Tablet	0.00	1.44	4.38	0.75	6.6
Laptop	0.06	1.72	4.39	0.44	6.6
Post Partum	Medications (2)	Numeric (6)	Demographic (4)	Narrative (30)	Total (42)
Paper	1.28	3.33	3.00	3.83	11.4
Tablet	0.86	2.50	2.71	2.57	8.6
Laptop	1.13	2.38	2.69	3.75	9.9
Medical Error	Medications (3)	Numeric (9)	Demographic (4)	Narrative (26)	Total (42)
Paper	2.50	1.44	2.81	5.75	12.5
Tablet	2.56	0.89	3.00	3.50	9.9
Laptop	2.43	1.00	2.21	4.14	9.8

Information on the number of items recalled based on technology and sorted by category of information type for each of the videos used can be found in Table 5. The total potential score for each category of information is listed in parentheses, beneath the category of information type. Each value in the table should be compared to the value in parentheses in the corresponding column of information type.

3.4 Gender

There was no significant effect of gender on either encoding or recall. During encoding females recorded 12.1 ± 0.6 items and males recorded 11.3 ± 0.6 items, and during recall females recalled 9.1 ± 0.6 items and males recalled 9.3 ± 0.6 items. However, there was significant interaction of gender and memory stage, and between encoding and recall females forgot an additional 1 item compared to males ($F(1, 38.17) = .538, p=.026$).

Females attended to more items than males initially and thus had the potential to forget more items. In the recall condition both females and males could recall the same number of items, which was approximately 9 items, the limit of working memory capacity.

Chapter Four

Study One Discussion

This study investigated the effects of input technology and environmental conditions on working memory for three different medical charting scenarios. Technology was manipulated in the form of changing the charting interface between paper, a tablet PC and a laptop, the three most feasible options for current medical charting practices (Anderson, 2009). Research in the field of memory suggested the importance of evaluating environmental factors for their effects on ability to recall information (Radvansky et al., 2011). Radvansky et al. (2011) demonstrated the effects of location updating effects, this phenomenon was the basis for the second hypothesis suggesting that more information would be recalled in the same environment as the videos were initially encoded. Finally, familiarity of information, gauged from self reported survey data was evaluated for an influence on performance scores. These results are discussed in detail in the following sections.

4.1 Technology

Parkinson and Khurana (2007) demonstrated that motor processes for well learned skills, handwriting among participants, aides in the process of letter recognition. Suggesting that the act of manual formation of text triggers traces in the long-term memory store that cannot be replicated through typing the same information. From this study it follows that recall performance on the medical charts completed using paper would be greater than the performance found from typing on either of the electronic platforms, the basis for hypothesis one.

The results showed a statistically significant effect of the input recording technology for both numbers of items recorded and recalled, and performance was superior for paper

compared with either a laptop or tablet PC, which did not differ. This finding supports hypothesis one, that there was an effect of technology. The information gathered from the follow up survey confirmed that paper was the preferred technology for recalling medical information for the participants tested and the general usage patterns highlighting the prevalence of paper use helps to explain how paper consistently outperformed the tablet PC and laptop for both note taking and recall. Laptops were the second most often used technology, however, the difference in performance between laptops and tablet PC was not statistically significant. Possible explanations for the lack of variation between performances on the electronic technologies could be attributed to the experience level of the participants tested. The training task that each participant completed was a brief exposure to the structure of the medical chart that would be used for data collection while the participant viewed a standard two-minute clip and recorded notes on the tablet. For many participants it was their first time using a Surface tablet, which could have caused lower performance than could be expected with more experienced users. Future iterations of research comparing the effects of technology should ensure that experience levels are reasonably balanced in order to make accurate comparison of performance. More training time and a separate task to familiarize participants with the structure of the medical chart could have improved the performance during the tablet PC charting condition.

While paper was the preferred method in this study, alternate research suggests the benefits and preferences towards electronic media for capturing notes due to the speed and security of having the information stored in one place (Shabbir et al., 2010). The benefits of manual writing help in recall, but come at a trade off of efficiency for capturing novel information (McAndrew et al., 2012; Schoen, 2009). In the context of this experiment the information presented to participants from the videos was dense and quick paced, suggesting that the laptop should have been the best technology to record the most

information while allowing the participants to focus on encoding the information rather than worrying about how much they could record on each of the devices.

Schoen (2009) studied the effects of manual handwriting compared to typing on performance of learning information from a lecture or textbook, and found that typing allowed for increased amount of information to be recorded which then lowered the cognitive strain of multitasking and allowed participants to recall more information in the follow up testing. Schoen's claim that typing was the superior method of input was, in part, due to efficiency of information transfer. A possible reason this claim was not supported by the present study could be the fact that regardless of the technology used each experimental video used lasted the same duration and participants were not prompted to finish their note taking or recall with any time pressure. Eliminating the pressures of completing a task in a fixed duration of time allows participants to reflect on the information as they initially record it, which could lead to improved levels of encoding, and subsequently performance increases on recall.

Table 2 helps to highlight the different types of information that were captured with the medical chart and their relationship with each technology interface. The last column in this table represents the total proportion of change that occurred between the first and second medical chart and provides a new perspective to evaluate the performance by. Although the paper technology allowed for more items to be recorded and recalled the proportion of successful recall was 10% less than the scores achieved by the tablet PC, where recall wasn't as extensive in value, however the proportion of original information that was encoded was more likely to be recalled. Beyond the comparisons that can be made between technology type for overall performance it is interesting to note the level of

difference between the types of information recalled, looking to the difference between the tablet PC, paper and laptop for the demographic category shows that for demographic information, the tablet interface may be too cumbersome to record specific demographic details, when compared on relying on basic human mechanisms of working memory. However once participants were given more time to reflect on the information they were able to populate that category of the chart more fully.

The error information that was recorded on the chart indicates the explanations to why there is a value in the table that is less than 1.0. Values equal to 1.0 indicate a perfect score between the first and second charting systems and show that no information was forgotten. Errors of omission refer to instances where the information was forgotten and that region of the chart was left blank, these errors were most common for narrative information, followed by demographic information and on rare occasion were observed for medication information. Errors of reversal describe a phenomenon in which numeric values were transposed, or simply recorded in the wrong area of the chart indicating that the value was still reported correctly, however the participant would provide heart rate information for temperature ratings, which was considered an error. These errors were most commonly observed for the numeric data that captured the vital signs portion of the medical charting template. The last error type that was found in this study was an error of generation, in which participants, rather than leaving a section of the chart blank to show an error of omission, would populate the chart with false information instead. These errors were predominately found in the demographic category of

information and would typically occur in the form of assigning a similar name to the name of the patient in the video.

Categorization of information in this way helps to explain the relationship of how information should be presented on each of the technological interfaces for the greatest level of performance among medical professionals. Further analysis of statistical differences between the occurrence of error type and the performance associated with technology type can influence the design of medical charting interfaces and lead to tangible design guidelines.

4.2 Environment

Surprisingly, the results for the effects of the environmental wait condition on the ability to recall information were not statistically significant, and there was no evidence of a location updating effect, as proposed by Radvansky et al. (2011), on the recall of medical information. Rather than observing a notable difference in number of items recalled after walking to a new location all observations were between the ranges of 9-9.4 items, it seems that the capacity limitations for working memory played a more significant role in determining the amount of information that was accurately recalled (Miller, 1956).

However, the present study was conducted in a laboratory rather than a real hospital and the participants were students rather than physicians and nurses. Future research might usefully explore whether or not a location updating effect can be confirmed in a real hospital and for real medical professionals. The fact that there was no significant location updating effect demonstrated through this study is relevant to the physical layout of reporting stations and current medical professionals already choose to complete a majority of their charting activities increasingly further from the patients bedside,

(Anderson, 2009) arguably the location at which the information was encoded. Potential explanations for the lack of environmental updating effect could be due to the fact that the second laboratory room, where information was recalled after the break, looked very familiar to the first room where the information was encoded. Radvansky et al. (2011) suggested one of the reasons that passage through doorways causes forgetting is due to the fact that there are often less retrieval cues in the new environment that can trigger working memory to produce the information needed. Since participants in the present study were traveling a short distance to a room that appeared to be very similar perhaps their cues used for transitioning recall were still present in the second room. Future research could require that participants move to more distinctly visually different locations to more accurately represent the transition from a patient room to a corridor or doctors office, locations where physicians are currently transitioning between to complete their charting tasks (Anderson, 2009).

Additionally, Radvansky et al. (2011) observed the location updating effects when prompting participants to recall visual stimuli, the aim of this experiment was to have participants recall auditory stimuli, which as Baddeley outlined relies on an entirely different system, the phonological loop (McLeod, 2012). Therefore there is reason to believe that if replicated with information that is accessed through the visuospatial sketchpad the location updating effect may be observed. Naka and Naoi (1995) suggested that the effect of encoding specificity relied on both technology cues of how information is encoded and recalled, and also relied heavily on the visual cues in the surrounding environment during encoding and recall. From this, it is feasible to state that the changing visual stimuli displaces information that was visually encoded, however has little or no effect on stimuli stored within the phonological loop.

4.3 Video Clip

There was a significant effect of the video clip on the number of items recorded and recalled, supporting the third hypothesis that familiarity of subject matter aides in recall. The subject matter of each clip was highly specific medical information pertaining to an error in communication among doctors prescribing medicine, a post partum hemorrhage trauma, and an educational diabetes care plan clip. Performance improvements in the diabetes clip could have been attributed to the fact that that information was more widely accessible and familiar than the information presented in the medical diagnostic error and the post partum video. This assumption is confirmed through the ratings on the post experimental survey. According to the post experimental survey results the Diabetes clip rated the highest among memorability, interest, understandability, enjoyment and overall video quality with an average score of .63 out of 1. The score for post Partum was .55 and for Medical error .52. Participants were also encouraged to leave additional comments or feedback regarding the experience with watching the medical clips and completing the charting activities. Comments suggested that the pace of the videos was at times difficult to process and they would prefer a system where they could pause the information to be able to record more information initially and retain more for subsequent charting activities.

Due to the fact that participants were not screened prior to experimentation for their levels of exposure to the subject matter of the video clips it was assumed that they all experienced similar levels of understanding of the medical conditions being presented in the video clips. The follow up survey was able to indicate which video was most preferred and easiest to understand, however the videos still did not capture the true experience of recording information in hospitals first hand. In order to eliminate unnecessary effects of quality or content of video clips future research should be conducted in actual hospital settings, amongst medical students on ward rounds. In a situation where multiple students

are recording notes on the same patients the effects of technology or a changing environment might be more easily discernable.

Table 5 reports actual mean values of information recalled after the 1-minute break for each of the videos used in this study. Values that are bolded indicate a situation in which more accurate information was captured than the video explicitly mentioned, for example the values for medication for the diabetes clips, when greater than 1 indicate that a participant selected the 'other' option and personally input medication information that wasn't provided by the list on the chart. Comparisons should be made across technology within each column of information type to help indicate which presentation of information lends itself best for performance scores for each of the three technologies.

4.4 Gender

There were no statistically significant effects of gender on the dependent variable, recall of information. Both males and females recalled roughly 9 items regardless of which clip was viewed or technology used. This is at the capacity limitations of working memory (Miller, 1956).

Schoen (2009) also evaluated gender in the performance of note taking based on handwriting and typing and found no differences between performance scores based on gender, although the balance between males and females in that study was heavily skewed to more females being represented. In the balanced study with equal number of male and female participants there were still no statistically significant effects of the amount of information that could be recalled, suggesting that future research does not require a gender balanced participant pool to study memory.

4.5 Limitations

Limitations to the study include small sample size and the lack of generalizability from using a sample of students from a University. Additionally, since students were not screened to ensure that English was their first language, a certain subset of the sample experienced great difficulty in understanding the videos of medical charting scenarios due to quick pace and seemingly advanced English medical jargon.

Pilot testing resolved issues in the original experimental procedure prior to data collection, however there were still a few conditions that could have been more explicitly described to avoid confusion. The walking within the single experimental room condition was notably the most difficult for participants to understand and perform without asking questions, simply standing still, or trying to leave the room. In future iterations of this research, experimenters should tape spots to the floor with signs saying walk back and forth from this mark to the next to provide more structure in that environmental waiting condition. The condition in which participants walked into a new room had some variability in the amount of time the participants were up and walking based on personal differences in gait, although the distance traveled remained the same among all participants.

Additionally, there were no intermediate distracter tasks that are typically used to avoid recency effects, where participants are more likely to recall information that was most recently presented, while studying human memory (Buchsbaum, 2010). While it was unclear from the present analysis if the information that was recalled was predominately information that was presented during the final seconds of the clip it could have been useful to include a distracter task between conditions of encoding and recall to ensure that each of the environmental waiting conditions required some alternate level of brain functioning to assess the amount of information that was actually learned during the viewing of the

medical clips. The two conditions where walking was employed as a form of distraction were matched on duration, however the distance traveled was minimal and may not have been a sufficiently different activity to clear the phonological loop from rehearsing what was previously viewed during the encoding stage of the video (Baddeley, 1988). By simply adding noise as a distraction between transitions the hospital environment could have been more accurately represented, and the chances of participant repetition or utilization of the phonological loop could have been avoided to more closely replicate real world settings.

Finally, the fact that the medical charts were structured for both the note taking and recall stages of the experiment could have influenced the level of information that was recalled since the identical formatting of the second chart could feasibly act as a trigger to the visuospatial sketchpad, prompting the recall of information that was previously encoded (Baddeley, 1988). Doebbeling (2009) suggested that the persistence of paper in medical facilities that have transitioned to electronic systems are now utilizing paper as a free form outlet of quick note taking that aides in the process of recall when physicians complete their charting activities after a delay, away from the patients bedside. Reich (2012) also considers how the reliance on technology changes the relationship to information and shows that the system of alerts and checks that are embedded within the technology allow for the attention of the medical professionals to be directed elsewhere. In order to represent a more realistic experience of what charting would be like in medical settings while in the laboratory context, free form notes could have been used for the encoding stage while allowing the structured chart to be introduced after a minute delay. Since the handwriting was already assumed to trigger memories, and the chart was identical in both encoding and recall stages the second stage could have acted as a fill in the blank type assessment which might not have adequately determined which information would translate to lasting information in the participants mind.

4.6 Study Two Rationale

While this research found an effect for the quality of using paper for both encoding and retrieval of medical information it did not provide a clear explanation of why. Previous research has shown a natural propensity to choose paper as the preferred medium (Schoen, 2009), and this effect was clearly replicated in the present study as 70.1% chose paper as their primary source of recording important to be remembered information. Despite participants' preferences toward paper Schoen's (2009) research supports the idea that typing is the best medium since it allows for a more efficient transfer of information and lets the brain focus on encoding rather than the motor skills necessary to form manual text through handwriting. Since there is debate of which technology affords the best opportunities for note taking and recall in the context of memory research it became important to uncover the mechanisms that supported paper as the superior system. The second study that was conducted in line with this research topic focused on evaluating the effects of the motor skills required during handwriting and compared that activity across paper and the tablet PC platforms.

Based on the confirmed third hypothesis in the first study, that familiarity led to greater levels of recall it was hypothesized that paper would again outperform handwriting with a stylus on a tablet PC in the second experiment. Hypothesis 1b was further studied matching the motor skills required for handwriting on paper to those of handwriting on a tablet PC using a stylus. Results from the second study should highlight which technology allows for greater performance independent of motor skills required for inputting information to the device.

Chapter 5

Methodology: Study two

This study evaluated the direct effects of the motor processing of handwriting and compared two technologies on which handwriting can be used, a tablet PC, and a sheet of paper.

5.1 Participants

Sixteen students from Cornell University (4 male, 12 female) were recruited through an electronic posting on a University recruiting site (SUSAN) and the use of flyers on campus, to participate in this study. View a copy of the flyer used for recruitment in the Appendix F. Participants received \$5 payment for their time after completing the 20 min study.

Participants' ages spanned from 18 – 22 years old with an average age of 21 years old. These participants were most familiar with using paper or laptops although 3 of them had used tablets on a regular basis, at least once a day. All but one of them reported preference towards paper for tasks specific to recall. The one who didn't typically use paper as a memory aid used a laptop instead.

5.2 Research Design

Two groups of participants comprised of 8 individuals, one group was entirely female and the other was equally mixed between males and females. Each group experienced the exact same variation of conditions as Study one allowing all participants to use both the paper, and tablet while charting. Every participant watched both medical clips, post partum and medical error, and was presented the information in combination with the technology in a balanced randomized order. Performance scores were assigned for both charts during the experimental condition in the exact way as done in Study one.

The independent variables for this study were the technology used, paper and tablet. The dependent variable was the number of items recalled on the second chart during the retrieval stage.

5.3 Setting & Apparatus

Setting was identical to study one, see Figure 2, however during Study two Room C was used and was set up with identical equipment as previously described.

Participants would enter the lab through the lobby space and be directed into Room C. This room has a window to they lobby space and is otherwise closed off. Participants would watch both videos of medical charting scenarios in this space.

5.4 Materials

Participants were provided with the same tablet PC as used in study 1 along with a stylus to record information. They were provided a sheet of paper and Bic pen for the paper charting condition.

5.5 Procedure

The process of obtaining consent and informing participants about the study was identical as done in Study one.

Participants were randomly assigned to conditions upon arrival. Eight unique combinations of video clip and technology conditions were created and assigned to members of the 2 groups. The conditions were equally distributed so that each video was shown for each of the different technology conditions to avoid any effects of the quality of the video. Each of the two videos had 42 potential pieces of information to record. Note taking on the tablet was completed using a stylus to mimic the motor skills required for

writing on paper, this was done using the Microsoft Paint application rather than using Microsoft Word as done in study one.

The timing and follow up survey for the second study was also identical to the first study however, since there were only two conditions and environment was no longer a factor being evaluated the process took approximately 20 minutes. During the one-minute break between viewing the video while charting and taking notes participants sat quietly and waited for the duration of their one -minute break before being presented with the second blank chart and asked to fill it out based on the previously watched video clip.

5.6 Data Analysis

Performance scores were assigned for both charts during the experimental condition. The first score reflects the number of items of information that the participant recorded while watching the clip and charting simultaneously and the second score relates to the number of items of information that were accurately recalled after experiencing the minute break between viewing the video and recalling the information.

Mixed model analysis was completed using multivariate statistical analysis software (SPSS version 21) to compare the number of items reported on the first charts (the note taking conditions- encoding stage) to the technology used and video clip. The same mixed model ANOVA was used to compare the number of items reported in the second chart (the retrieval condition) as well as to compare to the difference between number of items reported or their overall performance score. Pairwise comparisons were made for main and interaction effects. Bonferroni adjustment was used to control for the large number of comparisons being made.

The dependent variables that will be presented are:

DV1: Items reported in Encoding stage

DV2: Items reported in Retrieval stage

The results will be presented simultaneously for Encoding and Retrieval, highlighting the performance differences across the independent variable categories. Further they will be categorized by technology, video clip then gender.

Chapter Six Study Two Results

Encoding and Retrieval 6.1 Technology

Significantly more items were recorded on paper for both encoding, while watching the video clip, ($F(1,14)=11.085$ $p=.005$) and recall ($F(1,14)=10.145$ $p=.007$) than for the tablet. The results of the pairwise comparison for the encoding stage showed a significant difference between paper and tablet with $M=17.9\pm1.0$ items being recorded using paper, and 14.9 ± 1.0 recorded using the tablet. During the retrieval stage 12.4 ± 0.9 items were recalled using paper, and 9.9 ± 0.9 were recalled using the tablet. There was $2.9 \pm .9$ item difference ($p=.005$) between how much information was recorded using paper compared to hand writing using the tablet, irrespective of which video clip was playing and the gender of the participant.

Table 6: Proportion of items recalled based on technology used categorized by information type.

	Medications	Numeric	Demographic	Narrative	Total
Paper	1.00	0.49	1.06	0.73	.75
Tablet	1.14	0.39	1.08	0.64	.69
Average	1.07	0.44	1.07	0.68	
Error Type	None	Reversal & Omission	Generation, Reversal & Omission	Omission	

*Bolded values indicate generation of accurate information over the minute break.

6.2 Video Clip

There was a significant effect of clip ($F(1,14)=13.052$ $p=0.003$) on the number of items recorded while participants were watching the medical charting scenarios. During the retrieval stage there were no significant effects of video. There was a mean difference of $M=18.0\pm1.0$ items was recorded for the medical error video and $M= 11.9\pm0.9$ were recalled during retrieval. For the Post Partum video $M=14.8\pm1.0$ items were recorded during encoding and $M=10.4\pm0.9$ items were recalled during retrieval.

The pairwise comparisons for the encoding stage revealed $M=3.2$ item difference between average number of items recorded during each video clip, with more items recorded for the Medical Error clip ($p=.003$). Each video had exactly 42 items that could have been recorded.

Table 7: Mean number of items recalled based on video clip categorized by information type.

Medical Error	Medications (3)	Numeric (9)	Demographic (4)	Narrative (26)	Total (42)
Paper	3.00	1.38	2.75	5.63	12.75
Tablet	2.50	1.25	2.38	5.25	11.38
Post Partum	Medications (2)	Numeric (6)	Demographic (4)	Narrative (30)	Total (42)
Paper	1.25	3.13	2.38	5.63	12.38
Tablet	1.38	1.75	2.50	3.13	8.75

6.3 Gender

There were no significant effects of gender in encoding or retrieval stages. The estimated marginal mean values and standard errors are presented in Table 8. Females recorded $M=15.4 \pm 1.0$ items during encoding and recalled $M= 11.5 \pm 0.8$ items during retrieval. Males recorded 17.4 ± 1.7 items during encoding and recalled 10.9 ± 1.4 during retrieval.

Table 8: Mean number of items recorded and recalled based on Gender

Gender	Encoding		Retrieval		Difference
	Mean	S.E.	Mean	S.E.	
Female	15.4	1.0	11.5	0.8	3.9
Male	17.4	1.7	10.9	1.4	6.5

*Based on Estimated Marginal Means

Chapter Seven

Study Two Discussion

7.1 Technology

The purpose of this study evaluated the direct effects of the motor processing of handwriting and compared two technologies on which handwriting can be used, a tablet, and a sheet of paper. It was hypothesized (H1a) that familiarity with a technology would lend itself to greater performance; this was supported in both studies. The information gathered from the follow up survey confirmed that paper was the preferred technology for recalling medical information for the participants tested and the general usage patterns highlighting the prevalence of paper use helps to explain how paper consistently outperformed the tablet PC for both note taking and recall. Not a single participant selected the tablet as the preferred device used for a memory aide, suggesting potential unfamiliarity or active selection of alternative technologies. Any effects of lack of familiarity with the tablet should have been mitigated through use of the training activity where participants familiarized themselves with the chart formatting and layout on the tablet and took notes on the training video while watching to simulate a real experimental condition.

Hypothesis 1b suggested an effect of the motor memory associated with handwriting to be a factor contributing to the ability to recall information. The second study expanded upon this hypothesis and combined the effects of familiarity with motor skills and suggested that the paper would still be the superior technology platform to record and recall medical information. Despite using motor skills across both technology conditions in the second study the paper still showed that significantly more items were being recorded in the encoding stage ($M = 2.9$ items) and recalled during retrieval ($M = 2.5$ items). This finding suggests that familiarity could have a greater effect than motor skills used on determining which technology is the best platform for taking medical notes.

Table 6 helps to highlight the different types of information that were captured with the medical chart and their relationship with each technology interface, the paper and the tablet PC. The last column in this table represents the total proportion of change that occurred between the first and second medical chart and provides a new perspective to evaluate the performance by. Paper was not only the technology that allowed for the most information to be recorded and recalled, but also demonstrated the highest retention values when comparing baseline performance scores to the number of items recalled. Beyond the comparisons that can be made between technology type for overall performance it is interesting to note the level of difference between the types of information recalled, looking to the difference between the tablet PC and the paper for the medication category shows that for medication information, the tablet interface may be too cumbersome to record checkbox information, when compared on relying on basic human mechanisms of working memory. However once participants were given more time to reflect on the information they were able to populate that category of the chart more fully.

The error information that was recorded on the chart indicates the explanations to why there is a value in the table that is less than 1.0. Scores equal to 1.0 would indicate a perfect score between the first and second charting systems and show that no information was forgotten. Errors of omission refer to instances where the information was forgotten and that region of the chart was left blank, these errors were most common for narrative information, followed by demographic information and numeric information. Errors of reversal describe a phenomenon in which numeric values were transposed, or simply recorded in the wrong area of the chart indicating that the value was still reported correctly, however the participant would provide heart rate information for temperature ratings, which was considered an error. These errors were most commonly observed for the numeric data that captured the vital signs portion of the medical charting template, they

were occasionally observed for the demographic category of information also. The last error type that was found in this study was an error of generation, in which participants, rather than leaving a section of the chart blank to show an error of omission, would populate the chart with false information instead. These errors were predominately found in the demographic category of information and would typically occur in the form of assigning a similar name to the name of the patient in the video.

Categorization of information in this way helps to explain the relationship of how information should be presented on each of the technological interfaces for the greatest level of performance among medical professionals. Further analysis of statistical differences between the occurrence of error type and the performance associated with technology type can influence the design of medical charting interfaces and lead to tangible design guidelines.

Potential reasons that paper consistently outperformed the tablet PC for the recall of information could be due to the disparity between actual experience of writing with a pen and writing with a stylus. Post experimental surveys allowed participants to express comments on using the two systems and many users were not satisfied with the quality of output produced from using a stylus. Future research could benefit from recording the time it takes to record the same information by hand with a pen and while using the stylus as timing could have been a factor that limited the potential for recall while using the tablet PC. Also, the use of Microsoft Paint application may have been too cumbersome to allow for a realistic system of input on the tablet PC while using the stylus.

The environmental effects were not significant during the first study so they were left out from the second study in order to simplify the experimental design and analysis. During the first study participants experienced three different experimental waiting conditions, during the second they simply sat and waited in the same location as where the

video was viewed and the medical information was encoded. While this is not representative of actual practices in a hospital setting it helped to isolate the effects of the technology used on the performance of memory in medical charting.

Similar to the first study, the present study was conducted in a laboratory rather than a real hospital and the participants were students rather than physicians and nurses. Future research might usefully explore whether or not effects of technology usage can be confirmed in a real hospital and for real medical professionals.

7.2 Video Clip

Eliminating the laptop condition from this study allowed for the comparisons between video clips to be equally matched on information presented in each clip. The two clips that were used were the post partum video and the medical error video since they both had 42 discernable items of information and had rated similarly in the first experiment on interest and understanding. Ratings of .55 for the post partum and .51 for the medical error clip during the first study were achieved. Ratings during the second experiment were similar, .58, and .55, which demonstrates consistency among both groups of participants. Perfect ratings of level of interest and understanding would be equal to 1.0.

Surprisingly, after pairing the videos for level of interest and amount of information, there was a significant effect of the video clip on the number of items recorded but not for the number of items recalled. An average of 3.2 more items were recorded for the medical error clip than for the post partum clip, despite having the same number of items to potentially record. This could be a factor of increased levels of interest in that clip as compared to the post partum video, however the sample size should have lessened that effect. The fact that there was no statistically significant difference in the number of items recalled after the break during the retrieval stage suggests that the participants were being

limited by the capacity of their working memory eliminating further effects of video content or quality to impact their ability to recall information (Miller, 1956).

Table 7 reports actual mean values of information recalled after the 1-minute break for each of the videos used in this study. Comparisons should be made across technology within each column of information type to help indicate which presentation of information lends itself best for performance scores for each of the three technologies. The most variation between technologies based on video clip was observed in the post partum clip and the differences were noted through both narrative and numeric data.

Although the effects of the video were not observed in the recall stage of the experiment it would still be useful to conduct this research in actual hospital facilities to uncover the effects of technology use and environmental updating effects in the real world.

7.3 Limitations

Limitations to the study include small sample size (16 participants) and the lack of generalizability from using a sample of students from a University. Both age and familiarity with technology impact users ability to perform on the different technology devices and should be considered when extrapolating this research to real world settings. A limitation of the first study was the lack of standardization of recruiting fluent English speaking students, although that was specifically addressed during the recruitment of the second study levels of understanding or preference towards video clips did not increase as expected.

Similarly to the first study distraction tasks were not implemented in the second study to help avoid any recency effects. Future research should include distraction tasks as common in alternate memory research (Buchsbaum, 2010). The nature of the structured

charting interface being provided for both encoding notes and recall of information poses the same threats as mentioned in the first discussion, section 4.5.

7.4 Future directions

Paper has demonstrated its superior performance for both encoding of information and retrieval through both studies. Initially this finding was attributed to the motor skills associated with the formation of text during manual writing (Parkinson et al., 2007). The second study employed the same motor skills used in handwriting while asking participants to handwrite their responses on a tablet PC and paper. Paper again displayed superiority over the tablet PC for the purpose of encoding and retrieval of medical information, this is potentially due to the familiarity with paper among sampled participants and their propensity to choose that medium on their own for recording important notes. Future research should evaluate which specific features of the paper are most familiar and try to replicate key features in the virtual environment.

Additionally, studying the human processes of working memory in real medical settings rather than relying on the quality of videos could help highlight the fact that this phenomenon happens outside of laboratory settings in the real world. Even use of an actual charting system could highlight differences that were not captured through this research. The simple nature of the charting system developed for this task, see appendix 3, could have hindered the ability to locate certain information embedded within the chart due to lack of familiarity of participants. If this study was to be replicated in real hospital settings it should employ the use of current charting systems that the professionals are more familiar with to eliminate any chances of the layout of information impacting the amount of information that was recorded initially and recalled after the minute delay.

Guimbretiere (2013) has been developing paper augmented digital documents that combine an electronic input device with an actual pen to capture the strokes and other data related to what has been recorded. This technology could be used to tie the two worlds together in the future of medical charting practices (Guimbretiere, 2013). The system uses paper and an electronic pen that captures stroke information and relays it to a digital format for ease of editing, if this was to be used in hospitals medical professionals could continue to chart on paper by hand and still gain the benefits of having the connected database as the information they input is uploaded to the web.

Chapter Eight

Conclusion

This research found an effect of technology on individuals' ability to record notes and recall information. As previous research indicated an effect of motor memory associated with word formation in handwriting, this condition was observed to be preferred among participants for note taking and recall. The environmental location updating effect was not supported through the first study, and thus was not evaluated during the second. The performance scores rated similarly regardless of the environmental waiting condition the participant experienced. This is great news for doctors especially, since they most often complete their charting activities away from the patient's bedside. Future studies should evaluate if the location updating effect is observed through transitions between distinctly different environments and those findings can provide implications for the design of medical charting stations on hospital floors.

The unexpected results from this study are related to the effects of the video clips. Future iterations of this research should evaluate the effects of input technology and environmental factors in actual hospital settings to avoid the effects of the quality of the video and understand how actual trained medical professionals are affected by the transition from paper based charting to electronic systems using the charting templates they are most familiar with. If this study was completed on a group of medical students working on rounds, during which each person was recording information on the same patients, the students could be equipped with either paper, a tablet or a laptop and asked to complete their charting activities as normal. The comparison of performance between these students could indicate which technology allowed for greater amounts of input to be captured and thus highlight which system is best for recall of information. Further the students could be asked to complete their charting activities in various locations to test the

existence of the environmental location updating effect. Completing this experiment in this real world setting would demonstrate which system should be used in actual hospitals.

As the preliminary literature review suggested, the layout of the interface should be very thoroughly planned and designed with the ultimate user, the physicians, in mind. The transition from paper to electronic medical systems in hospitals is a challenging time in which many additional errors can occur. In order to avoid potentially detrimental errors related to the physicians' memory of what is happening and how to correctly document it the systems should most closely resemble paper charts. Some hospitals have taken to using both paper and electronic charting in tandem, during the transition phase that is highly recommended on the premise of patient health and safety. Further research is required to determine exactly what it is about charting on paper that allows for increased performance and ability to recall information. While this study demonstrated a clear preference towards paper for both encoding and retrieval of information there are benefits described by previous research to using electronic systems, these include the speed and accuracy of information capture, along with the increased transparency and improved communication between different members of the charting team. The fact that electronic systems can put in place a system of alerts and checks for the diagnosis is also reassuring when it comes to error prevention in hospitals. These qualities all need to be weighed in respect to the performance increases found with paper charting systems for hospitals to decide which system is best to subscribe too for their medical charting needs.

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Appendix A

ANOVA Tables of Fixed Effects

Study 1: ANOVA Table of Fixed Effects, Dependent Variable number of items recorded during Encoding.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	39.870	807.036	.000
Gender	1	38.115	1.048	.312
Environment	2	79.820	.851	.431
Technology	2	79.842	17.260	.000
Video Clip	2	79.842	61.714	.000
Environment * Technology	4	74.177	.361	.836
Environment * Video Clip	4	74.441	.174	.951
Technology * Video Clip	4	63.220	.394	.812
Environment * Technology * Video Clip	8	83.049	.663	.723

Study 1: ANOVA Table of Fixed Effects, Dependent Variable number of items recalled during Retrieval stage after 1 minute environmental wait condition.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	39.861	488.386	.000
Gender	1	38.088	.077	.783
Environment	2	79.604	.397	.674
Technology	2	79.628	7.338	.001
Video Clip	2	79.628	34.442	.000
Environment * Technology	4	71.719	.854	.496
Environment * Video Clip	4	71.786	.284	.887
Technology * Video Clip	4	60.165	.298	.878
Environment * Technology * Video Clip	8	80.534	.986	.454

Study 2: ANOVA Table of Fixed Effects, Dependent Variable number of items recorded during encoding.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	13	298.884	.000
Gender	1	13	.973	.342
Technology	1	14	11.085	.005
Video Clip	1	14	13.052	.003
Technology * Video Clip	1	13	.002	.963

Study 2: ANOVA Table of Fixed Effects, Dependent Variable number of items recalled after 1 minute break.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	13	204.635	.000
Gender	1	13	.134	.720
Technology	1	14	10.145	.007
Video Clip	1	14	3.652	.077
Technology * Video Clip	1	13	.490	.496

Appendix B

Pairwise Comparisons

Pairwise Comparisons of Technology used during Encoding stage. (Study 1)

(I) technology	Mean Difference (I-J)	Std. Error	df	Sig. ^c	95% Confidence Interval for Difference ^c	
					Lower Bound	Upper Bound
Paper Tablet	3.744*	.638	80.378	.000	2.185	5.302
Laptop	1.679*	.634	80.842	.029	.128	3.230
Tablet Paper	-3.744*	.638	80.378	.000	-5.302	-2.185
Laptop	-2.065*	.648	78.268	.006	-3.650	-.480
Laptop Paper	-1.679*	.634	80.842	.029	-3.230	-.128
Tablet	2.065*	.648	78.268	.006	.480	3.650

Based on estimated marginal means

Pairwise Comparisons of Technology used during Retrieval stage. (Study 1)

(I) technum	Mean Difference (I-J)	Std. Error	df	Sig. ^c	95% Confidence Interval for Difference ^c	
					Lower Bound	Upper Bound
Paper Tablet	1.907*	.519	80.136	.001	.638	3.177
Laptop	1.409*	.517	80.722	.024	.145	2.673
Tablet Paper	-1.907*	.519	80.136	.001	-3.177	-.638
Laptop	-.498	.526	77.984	1.000	-1.785	.789
Laptop Paper	-1.409*	.517	80.722	.024	-2.673	-.145
Tablet	.498	.526	77.984	1.000	-.789	1.785

Based on estimated marginal means

Pairwise comparisons between technology and number of items recorded in encoding stage. (Study 2)

(I) technology	Mean Difference (I-J)	Std. Error	df	Sig. ^c	95% Confidence Interval for Difference ^c	
					Lower Bound	Upper Bound
Paper Tablet	2.938*	.882	14	.005	1.045	4.830
Tablet Paper	-2.938*	.882	14	.005	-4.830	-1.045

Based on estimated marginal means

Pairwise comparisons between technology and number of items recorded in retrieval stage. (Study 2)

(I) technology	Mean Difference (I-J)	Std. Error	df	Sig. ^c	95% Confidence Interval for Difference ^c	
					Lower Bound	Upper Bound
Paper Tablet	2.500*	.785	14	.007	.817	4.183
Tablet Paper	-2.500*	.785	14	.007	-4.183	-.817

Based on estimated marginal means

Pairwise comparisons between video clip and number of items recorded in encoding stage. (Study 2)

(I) clip	Mean Difference (I-J)	Std. Error	df	Sig. ^c	95% Confidence Interval for Difference ^c	
					Lower Bound	Upper Bound
Medical Error Post Partum Hemorrhage	3.188*	.882	14	.003	1.295	5.080
Post Partum Hemorrhage Medical Error	-3.188*	.882	14	.003	-5.080	-1.295

Based on estimated marginal means

Appendix C

Medical Charting Template

Admission Date: _____

Today's Date: _____

Demographic information

Name:		DOB:	Allergies:
Gender:	Race:	Age:	Immunizations:
Height:	Weight:	Social History: place an X on the line below ___ Single ___ Married ___ Widowed ___ Divorced	

Reason for admittance:

Medications: place an X on the line for any medications being used.

___ Percocet	___ Acetaminophen	___ Ambient	___ Lipitor	___ Lisinopril	___ N/A
___ Digoxin	___ Rosuvastatin	___ Coumadin	___ Heparin	___ Norvasc	___ Other

Attending Physician/Team: _____

Past Medical History:

History of present illness:

Vital Signs

Blood Pressure: /	Blood Sugar Level:	Respiration:	Temp:
Heart Rate:	Insulin Dosage:	O ₂ level:	

Prescribed Treatment:

Notes:

Appendix D

Consent form

Today I am asking you to participate in a research study. This form is designed to give you information about this study. I will describe this study to you and answer any of your questions.

Project Title: Medical Charting Assessment

Principal Investigator: Angela Spangler
Design & Environmental Analysis
Email: ams748@cornell.edu

Faculty Advisor: Alan Hedge
Design & Environmental Analysis
Email: ah29@cornell.edu

What the study is about

The purpose of this research is to study the different technologies nurses use in medical charting.

What we will ask you to do

After a brief training video and practice using the tablet, I will ask you to watch three short video clips that are each two minutes long. During the video you will be given a blank medical chart that you will fill in as much information as could be gathered from the short clip. You will take a short break and then be asked to fill in the form again.

Risks and discomforts

I do not anticipate any risks from participating in this research.

Benefits

There are no direct benefits from participating in this research.

Payment for participation

You will receive \$5 for participating in this study.

Privacy/Confidentiality

After signing this form you will be given a unique identification number that will be used in lieu of your name for storing data. Your name will only appear on these records and for all future analysis your number will be used in order to protect your privacy and keep all responses confidential.

Taking part is voluntary

Participation in this study is completely voluntary. You may reserve the right to refuse to participate before the study begins, discontinue at any time, or skip any questions/procedures that may make you feel uncomfortable, with no penalty, and no effect on the compensation earned before withdrawing, or your academic standing, record, or relationship with the university.

If you have questions

The main researcher conducting this study is Angela Spangler, a graduate student at Cornell University. Please ask any questions you have now. If you have questions later, you may

contact Angela Spangler at ams748@cornell.edu or contact Alan Hedge ah29@cornell.edu. If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) for Human Participants at 607-255-5138 or access their website at <http://www.irb.cornell.edu>. You may also report your concerns or complaints anonymously through Ethicspoint online at www.hotline.cornell.edu or by calling toll free at 1-866-293-3077. Ethicspoint is an independent organization that serves as a liaison between the University and the person bringing the complaint so that anonymity can be ensured.

You will be given a copy of this form to keep for your records.

Statement of Consent

I have read the above information, and have received answers to any questions I asked. I consent to take part in the study.

Your Signature _____ Date _____

Your Name (printed) _____

Signature of person obtaining consent _____ Date _____

Printed name of person obtaining consent _____

This consent form will be kept by the researcher for at least five years beyond the end of the study.

Appendix E

Post Experiment Survey

Identification Number: _____ Age: _____ Major: _____

Year in School: ____ Freshman ____ Sophomore ____ Junior ____ Senior ____ Grad

Pre-Med: ____ yes ____ no

1. NOTE TAKING: On the blank next to each technology please indicate the percentage of time that you find yourself using that technology to take notes.

(If you only use one then write 100% on that line and leave the others blank)

_____ Paper

_____ Tablet

_____ Laptop

2. GENERAL USE: On a typical day how many hours do you use each of the following technologies?

_____ Paper

_____ Tablet

_____ Laptop

3. MEMORY: Which technology would you use if you were interested in remembering a specific piece of information? (highlight one)

a. A form of paper

b. A personal tablet

c. A laptop computer

4. Please fill in the table below with values from 1-10. 1= least, 10 = most

	Post Partum Hemorrhage (Mrs. Woolf)	Medical Error (Mr. Waters)	Diabetes education (Mr. Zoreb)
Memorable			
Interesting			
Understandable			
Enjoyable			
Quality of information			

5. Please provide any additional feedback or comments about the videos below:

Appendix F

Flyer



Influence the Future of Medical Charting

Would you like to impact the future of medical charting technologies?

Are you looking for an easy \$5?

Join me, Angela Spangler, for 30 min. as I study technology use in medical charting.

Requirements:

- A full time Student at Cornell
- Between the ages of 18-25 years old
- A fluent English Speaker

Location:

HEB116

For more information and to schedule participation, contact me directly at: ams748@cornell.edu or (208) 891-1355
Thanks!